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TEMPERATURE SURVEY OF THE SALT RIVER VALLEY, ARIZONA.

551.524 (791)

By JAMES H. GORDON, Observer.

[Weather Bureau, Yuma, Ariz., Apr. 21, 1921.]

SYNOPSIS.

In 1913 an investigation was begun to determine within what limits the foothill sections of the Salt River Valley in the vicinity of Phoenix were adapted to citrus culture. Later the scope of the investigation was broadened to include a study of winter temperatures over the whole valley. Upon the basis of records kept at more than 40 stations in the area considered a temperature map was drawn showing the mean minimum temperatures for December and January; the average length of the growing season in the different sections of the valley was determined; a basis was established for forecasting minimum temperatures in the various sections as related to the temperatures expected at the Weather Bureau station in Phoenix; in short, data on winter minimum temperature conditions throughout the valley were gathered and put into such shape as to be useful not only to the citrus grower but to all ranchers, to all intending land buyers, to men looking for the best location for any particular crop and, as it developed, to health seekers searching for the best vantage ground from which to make their fight against tuberculosis. Work during the winter of 1919–20 was directed almost exclusively to the study of temperature inversion as found over the valley, a cross section from the hills on the north down across the Salt River and up into the hills on the south affording an excellent opportunity for such a study.

With the completion of the Roosevelt Dam and distributing system in the Salt River Valley early in 1911, an era of rapid development of the section about Phoenix began. Oranges and grape fruit had been successful in a small way and greatly increased acreage was planted; the growing of sugar beets and sugar cane was undertaken on a large scale; experiments were made in growing figs, grapes, olives, dates, cotton, and many other products. The winters of 1911–12 and 1912–13 were unusually severe. Many of the experiments had been made blindly and were failures. Not all of the failures were due to the severe winters, but killing frosts also had been a contributing cause in many cases. Men were learning to use the soil and water to advantage. Need was felt for a more definite knowledge of winter temperature conditions and it was to supply this need that the survey was undertaken.

The work was started in the fall of 1913 by the late Robert R. Briggs, "to determine the area and limits within which the highest money-value crops could be grown." Citrus groves in favored locations had come through the preceding severe winters with little damage. The fruit ripened early, several weeks ahead of the California product, and brought top prices. The first aim of the survey was to determine what areas were suited to the growing of this highly profitable crop. During the winter of 1913–14 four minimum thermometers were lent to orchardists and exposed in improvised shelters; and one privately equipped station was maintained. Two regular stations had been established also, one in the lowest part of the valley on the river, and the other at Marinette, near the western limit of the area, being studied, where several hundred acres had been planted to sugar cane. Results obtained from these stations showed the need of much more thorough covering of the valley with observing stations.

A much more ambitious program was carried out during the winter of 1914–15. Standard equipment was installed at the four stations already located and seven new stations were established. Twelve thermographs aided very materially in securing good records providing a check against all recorded thermometer readings and bridging over periods where thermometer readings were not taken. Results of this season's work are contained in an unusually elaborate report prepared by the late Robert R. Briggs in July, 1915. No attempt was made to draw conclusions at this early stage of the survey, but the report formed a groundwork for future deductions and suggested lines of development for the investigation.

A visit from the Chief of the Weather Bureau in the spring of 1915 and his interest in the survey gave new impetus to the work. The winter of 1915–16 began very promisingly. Arrangements were made for a much closer supervision of the work, with frequent visits to all stations. Three outfits were shifted to locations where better observational work was promised. The death of Mr. Briggs in January was a severe blow to the survey, as his unfailing interest and enthusiasm had met and overcome many obstacles. The work was continued to the end of the season under the direction of the late Kenneth Meaker, and results were decidedly the best to date in both completeness and accuracy.

Throughout the winters of 1916–17 and 1917–18 the work was carried on under the direction of Meteorologist Robert Q. Grant with but little change aside from the necessary shifting of some stations to secure better cooperation in the keeping of records. The problem of visiting the widely scattered stations frequently enough to keep all the work well in hand was not satisfactorily solved, but much of the work was well done and the mass of reliable data on temperature conditions grew steadily. At the end of the 1917–18 season it was felt that sufficient material had been gathered to map the various sections of the valley.

In the fall of 1917, following a visit to the valley and a study of the results obtained from the survey, Meteorologist William G. Reed recommended that a supplementary series of observations be made to give a temperature cross-section of the valley from north to south. In accordance with these recommendations, the location of stations to give the cross-section was arranged during the summer of 1918. The death of Observer Kenneth Meaker in November left the office too short-handed to undertake the work of moving and setting up the necessary stations and visiting them each week until early in February. Six new stations were established and used in connection with four old stations to form an approximate north and south line fourteen miles long reaching from the Phoenix Mountains, Squaw Peak, on the north down across the river and up into the Salt River Mountains on the south. Records were kept going until April and while no severe temperatures occurred excellent radiation conditions prevailed much of the time and a good foundation was laid for the next season's work.

In many respects the records of 1919-20 were the most satisfactory of the entire survey. Thermographs had been carefully adjusted and almost without exception gave excellent results. The station most difficult to visit was shifted slightly to a location where an observer was available; and one new station was established in a newly opened section which promised to offer very good prospects for citrus fruits. An arrangement was made with the Southwest Cotton Company for free-air temperatures to be taken by airplane at various elevations over the cross-section during cold, early mornings. Unfortunately, the plane was wrecked before this work could be started. These data, if available, would offer a most interesting comparison with hillside temperatures at the same elevation at the same time. The winter's work began November 1 and continued through the first week of April. Weekly visits were made to eight stations during this period and occasional visits to other stations as opportunity offered. The records obtained are especially interesting as bearing on the study of temperature inversion and air drainage, and, with certain illustrative tracings and graphs, are taken up in the latter part of this report.

In all, 42 stations were considered in making up the report of the survey, 13 of them regular stations, of which 2 are outside the valley proper, and 29 special stations. Credit is due to many cooperative observers in making the report so complete. The results have been worth while. There has already been a considerable demand for copies of the printed map showing temperature lines and length of growing season over the valley. The value to health seekers alone would justify the last season's work. It is felt that in a much larger measure than was at first contemplated the object of the survey, "to determine the area and limits within which the greatest money value crops could be grown," has been attained.

Notes on temperature map.—In making up this temperature map of the Salt River Valley (see chart) mean minimum temperatures for December and January were used, particularly because they were the coldest months of the year, but also because for these months more complete figures were available than for November and February. While for many of the more than 40 stations considered the records were too short to give a fair mean of themselves a number of long records were available, 25 years at Phoenix Weather Bureau Station, 24 at Granite Reef Dam, 20 at Mesa and the University Experiment Farm (Phoenix No. 1), and 16 at Tempe. For these long records minimum-temperature normals were worked out for December and January and departures from the normal figured for each month. These departures were applied as corrections to temperatures at short-record stations for the appropriate months, zones being established over which corrections from the different long records should be applied.

Relation of the mean minimum temperature to the absolute minimum.—It must be admitted that the map fails to touch directly on the very vital subject of absolute low temperatures, the temperatures which damage and against which the gardener, nurseryman, and orchardist must be on his guard. And yet the relationship between these temperatures and the mean minimum is very close. As shown by the following table, which embodies the results of all records of five years or more, there is a difference between the mean minimum and the mean absolute minimum, by months, which very closely approximates 11° F. The difference is so consistently shown by the nine records considered that it probably may be safely applied to all. A further allowance of 8 degrees will cover all probable departures from this mean of the absolute minimum though during the record-breaking cold period in January, 1913, the departure was from 12 to 14 degrees; 4 to 6 degrees greater than for any other year which the record covers.

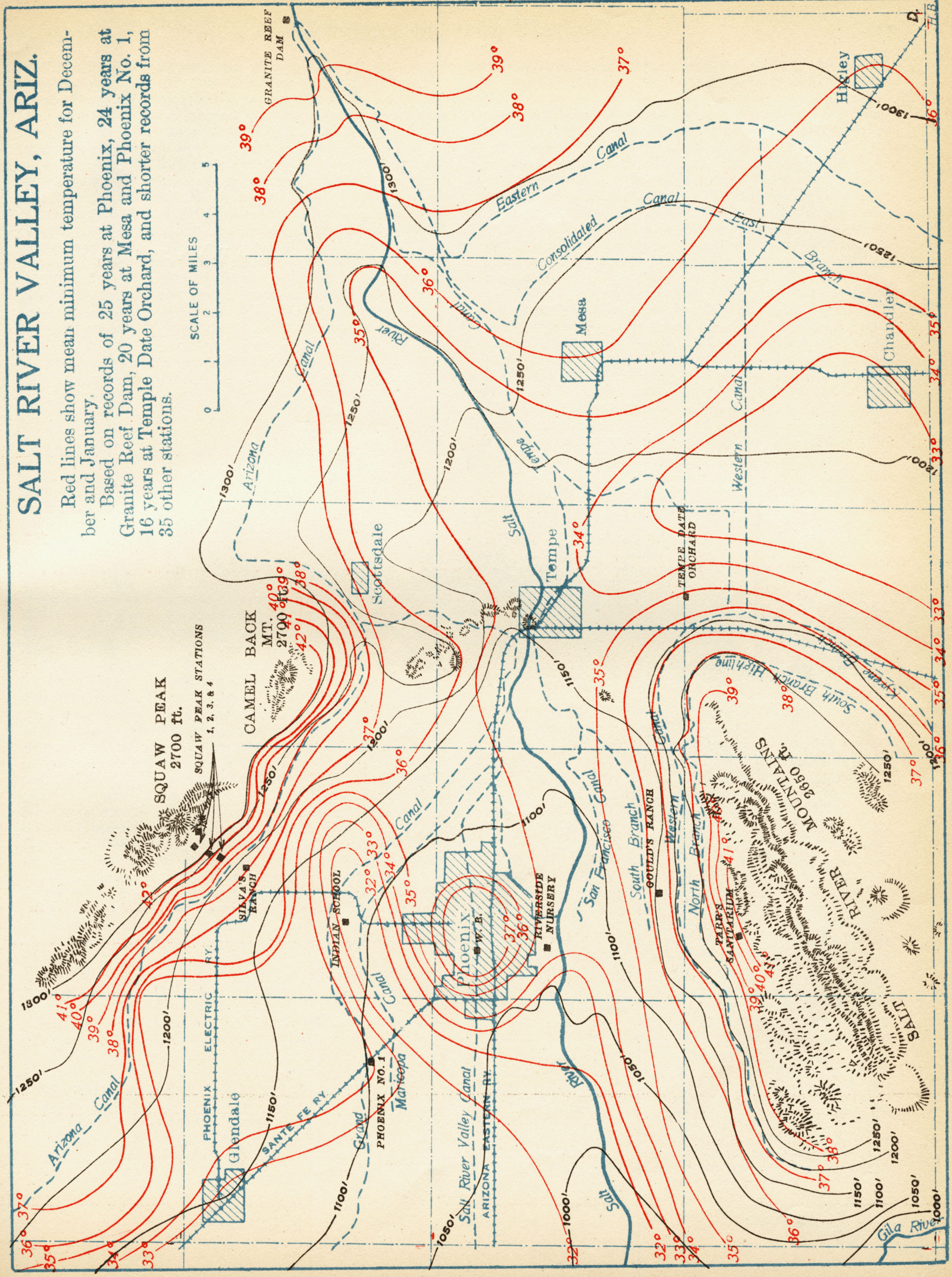
TABLE 1.—*Comparison of mean minimum and absolute minimum temperatures.*

Station.	Length record.	Mean minimum temperature.	Mean absolute minimum temperature.	Difference.	Minimum January, 1913.
	Years.	°F.	°F.	°F.	°F.
Granite Reef Dam	21	40.0	28.8	−11.2	13
Phoenix Weather Bureau	25	38.5	28.0	−10.5	16
Phoenix No. 2	6	37.5	26.6	−10.9	14
Gould's Ranch	5	37.0	25.8	−11.2	(1)
Mesa	18	36.0	25.4	−10.6	(1)
Higley	5	36.0	24.8	−11.2	(1)
Tempe	15	35.0	24.4	−10.6	12
Phœnix No. 1	18	34.5	23.4	−11.1	11
Chandler	6	33.0	23.1	−9.9	9
Average difference				−10.8	

[1] Record for January, 1913, missing.

Forecasting minimum temperatures.—In issuing frost warnings the value of the forecast is greatly increased by giving the minimum to be expected in each locality. It has been found possible to forecast minima for Phoenix very closely. In the case of extreme or dangerous temperatures the average difference in minima to be expected at Phoenix and any other station in the valley will closely approximate the difference shown by the lines on the map. This is true as an average. In practice, each forecast must be made with a remembrance of the several possible modifying elements. On nights with considerable wind, the difference will be decreased or even reversed occasionally; that is, if the wind persists throughout the night. A calm of three or four hours, even from 4 a. m. on, is sufficient to establish approximately the differences shown on the map. On still, exceptionally good radiation nights the difference will be increased as much as 50 or 60 per cent. In the case of cold waves sweeping down from the north it is not unusual for stations in the southern sections of the valley to be 24 hours later than the northern stations to feel the cold.

Value of the 6 p. m. dew-point in forecasting minimum temperatures.—The 6 p. m. dew-point shown at the Phoenix Station of the Weather Bureau, while of value in forecasting minima likely to occur in Phoenix the following morning, seems to have little value in forecasting minima to be expected in the colder sections of the valley. During the months of November, December, January, and February, 1919-20 season, following clear, good radiation nights, minima at the Indian School, 3 miles north of Phoenix, *averaged* 6 degrees lower than the mean 6 p. m. dew-point of the preceding evenings


SALT RIVER VALLEY, ARIZ.
Red lines show mean minimum temperature for December and January.
Based on records of 25 years at Phoenix, 24 years at Granite Reef Dam, 20 years at Mesa and Phoenix No. 1, 16 years at Temple Date Orchard, and shorter records from 35 other stations.
SCALE OF MILES
0 1 2 3 4 5
GRANITE REEF DAM
Eastern Canal
Consolidated Canal
East Branch
Mesa
Higley
Chandler
Western Canal
Arizona Canal
Salt River
Scottsdale
Tempe
TEMPE DATE ORCHARD
CAMEL BACK MT. 2700 ft.
SQUAW PEAK 2700 ft.
SQUAW PEAK STATIONS 1, 2, 3, & 4
SILVA'S RANCH
INDIAN SCHOOL
Grand Canal
Phoenix
W. B.
RIVERSIDE NURSERY
San Francisco Canal
South Branch
GOULD'S RANCH
North Branch
PARR'S SANATARIUM
South Branch Highline
SALT RIVER MOUNTAINS 2650 ft.
PHOENIX NO. 1
Maricopa Canal
PHOENIX ELECTRIC RY.
SANTE FE RY
Glendale
Salt River Valley Canal
ARIZONA EASTERN RY.
Gila River
D.

in Phoenix. In one case the minimum was 14° lower than the dew-point of the preceding evening. Through these months the morning dew-point is normally lower than that at 6 p. m. preceding, but even this will not bring the 6 a. m. dew-point at Phoenix down to the minimum at the Indian school. In extreme cases, the minimum was 7° lower than the 6 a. m. dew-point at Phoenix, while the average difference for the four months was minus three degrees.

Length of the growing season.—For stations with a length of record of five years or more the length of the growing season has been worked out in its relation to the 38.5°, or Phoenix, temperature line as a base. It is realized that the five-year records are too short to be conclusive, but in the absence of longer records several have been used to fill out the scale. The average length of the growing season in Phoenix is 288 days.

TABLE 2.—*Length of the growing season.*

Station.	Length record.	Mean min. temperature.	Season as compared with Phoenix.
	Years.	*°F.*	*Days.*
Granite Reef Dam	16	40.0	+5.0
Phoenix Weather Bureau	25	38.5	0.0
Phoenix No. 2	5	37.5	−1.2
Gould's Ranch	5	37.0	−2.8
Mesa	11	36.0	−17.5
Higley	5	36.0	−18.5
Tempe	14	35.0	−19.0
Phoenix No. 1	11	34.5	−22.0
Chandler	5	33.0	−31.0

There is no question that some of the hillside exposures will give a growing season fully a month longer than Phoenix, but data are not available on which to base exact figures.

The citrus belt and frost protection.—A primary object of the survey was to determine what sections were suitable for citrus culture. The scope of the survey broadened considerably, but sight was not lost of the original idea. While citrus trees grow and there are a few small groves as low as the 34° line, on the map the citrus section of the valley lies above the 35° line and the most desirable sections above the 36° line. The fact that the fruit is nearly always off the trees before the first frost and that the trees are in a semidormant condition through the winter season makes the danger of loss from low temperature, once the trees have made a good start, less than for citrus sections of California. Smudging and flooding as a protection agianst frost are confined almost exclusively to young groves and nurseries. In exceptional cases, where frost is expected and the fruit has not been gathered, picking is rushed all day and far into the night as damage to the fruit rather than to the trees is the danger.

For health seekers.—Health seekers and elderly people who come to the Salt River Valley for the winter have two faults to find with the climate. One is the great diurnal range in temperature and the other is the comparatively high humidity which accompanies the chill of early morning. The climate of the hillsides overlooking the valley is free from these faults. The temperature range will average from six to ten degrees less than on the floor of the valley and this decrease in range comes mostly at the cold end of the day. The chill of the early morning is missing and with it the objectionable high humidity. Few places in the world can offer a more nearly ideal winter climate than these hillsides with the abundant, healing sunshine and warm days of the desert, but without its great temperature range and chill mornings.

Inversion of temperature and air drainage.—The position of the temperature lines on the map in their relation to the contours of elevation establishes the fact of temperature inversion over the Salt River Valley. But the lines also establish the fact that this condition of inversion is not without complications. The area of low temperature lying midway down the slope from the northern hills to the river is the most self-evident inconsistency while the relatively high temperature shown at Phoenix and Riverside Nursery, farther down the slope, call for explanation.

To permit a more detailed study of this inversion layer nine stations were established in the spring of 1919 crossing the valley from north to south. Starting in the north ot Squaw Peak No. 4, 1,750 feet elevation, the line dips down to Riverside Nursery at 1,075 feet, on the north bank of the Salt River, and rises again to 1,400 feet at Tarr's Sanitarium. The total length of the line is 14 miles. The accompanying graphs and thermograph tracings summarize and illustrate the result of a study of the records of temperatures along this cross-section for the season 1919–20.

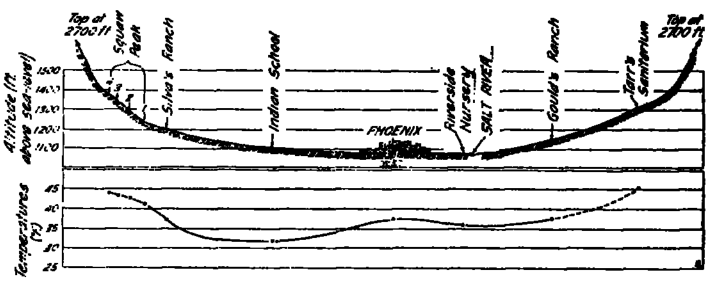


FIG. 1.—A cross-section of the Salt River Valley, Ariz. The upper graph shows a topographic cross-section, and the lower the mean minimum temperatures for December and January along the same section.

The graph showing temperature cross-section of the valley is based on mean minimum temperatures for December and January shown at the stations with correction, given by the long Phoenix record, necessary to reduce them to a true mean. Along this particular line it is apparent that a considerable mass of air at the lower levels fails to show the condition of inversion. The lowest temperature is shown at the Indian School, which is 25 feet higher than Phoenix and 40 feet higher than Riverside Nursery. The map offers an explanation for this seeming inconsistency. It will be observed that the canals north of Phoenix show a wide curve convex toward the mountains. The depression or secondary valley so indicated crosses the slope of the valley proper diagonally from northeast to southwest. It is so slight a depression as to escape entirely the notice of one passing over the ground, with a depth of only about 25 feet and a width of more than 4 miles, but it offers a channel for the cold air streams draining down from the slopes to the north and east. This area with a mean minimum temperature of 32° or lower, shown on the map, is in this flat valley and gets the full benefit of this cold air stream. Land on the south is warmer because of this diversion of the cold air to the southwest, even though of lower elevation than the floor of the subvalley. The relatively high temperatures shown by the Phoenix station of the Weather Bureau, while probably due in considerable measure to the city influence almost certainly are higher because protected from cold air draining down from the north.

Riverside Nursery is protected on the north both by the diversion of the cold air stream and by the city of Phoenix itself with its warming influence. Protection on the south is afforded by the broad bed of the Salt River, which diverts cold air draining from hills on the south to the west. Riverside Nursery is three or four degrees warmer than might be expected if elevation, in relation to the other stations considered, were the determining factor.

The inversion layer appears to have its base some 40 feet above the lowest elevation shown in the section, at least on the north side of the valley. In a general way, this layer may be thought of as made up of superimposed, approximately horizontal air strata in which the temperature rises with the increase in elevation. The positions of the strata within the layer are subject to constant change from the moment the condition of inversion begins, usually late in the afternoon, until the condition is ended by the rising temperatures of the following morning. We are more particularly interested in conditions within the layer at the time of minimum temperature as that is the time at which almost invariably

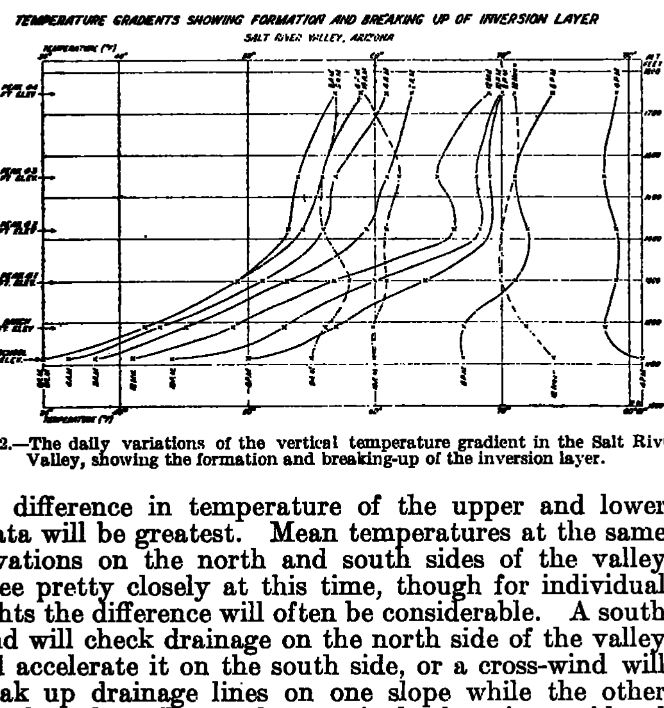


FIG. 2.—The daily variations of the vertical temperature gradient in the Salt River Valley, showing the formation and breaking-up of the inversion layer.

the difference in temperature of the upper and lower strata will be greatest. Mean temperatures at the same elevations on the north and south sides of the valley agree pretty closely at this time, though for individual nights the difference will often be considerable. A south wind will check drainage on the north side of the valley and accelerate it on the south side, or a cross-wind will break up drainage lines on one slope while the other may be calm. Even where a single slope is considered there is a constant variation in the inversion layer from night to night. The section of the layer in which the rate of vertical change is greatest shifts up and down, the depth of the layer almost certainly changes. No two nights show identical records.

It is in relation to study of inversion on a single slope comparatively free from complicating topographic features that most of the graphs and thermograph tracings were made up. The Indian School, being at the foot of the slope drained, is taken as a base and five other stations on an unbroken slope rising 635 feet above it offer excellent opportunity for a study of temperatures within the layer. The thermograph tracings show the development of the inversion condition, as does one set of graphs, from the time of maximum temperature on the preceding day to the time of minimum and the rise of temperature the following morning. Other graphs show simply the temperature gradient within the layer at the time of minimum temperature and represent the mean of a number of days.

Relative humidity appears to be a factor in determining the contrasts of temperature within the inversion layer. Where a number of consecutive mornings are considered, that one with the highest humidity the preceding evening almost invariably shows the smallest contrasts of temperature in the inversion layer. The graphs show the decrease in temperature contrasts through November, December, January, and February, while in March there was a sharp increase. Records show that the mean 6 p. m. relative humidity increased from November through February and dropped sharply in March. It is also suggested that the cooling of the earth itself, the gradual loss of accumulated heat with the advance of winter, may partly explain the progressive decreases in temperature contrast shown by the gradients of December, January, and February, and the increase with the higher day temperatures of March. In other words, there is less heat radiated from the earth itself to influence the temperature of the upper strata of the inversion layer.

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DAILY TEMPERATURE VARIATIONS AT THE SURFACE OF THE GROUND IN HOT ARID CLIMATES.

By PAUL RANGE.

[Abstracted from *Meteorologische Zeitschrift*, Mar.–Apr., 1920, pp. 102-104.]

It is of value in studying the effects of erosion to observe the variations of temperature of the upper layers of the ground, because it is certain that such variations play considerable part in the disintegration of the rocks, especially where they are composed of minerals having different coefficients of expansion. Such observations were made for two and one-half years at Kuibis, in German Southwest Africa. Kuibis is 1308 meters above sea level, and lies 175 km. inland from the Atlantic Ocean. Observations were made with a mercurial thermometer possessing a black bulb in an evacuated chamber; an Arago-Davy Actinometer, which is a similarly constructed instrument with an unblackened bulb; a mercurial maximum thermometer and an alcohol minimum thermometer. Observations were made in the air and on the surface of the ground.

The black-bulb thermometer readings averaged 8° C. higher on the ground then in the air for the year, probably owing to the nature of the soil. The following table shows the air and ground temperatures for the year:

	Minimum.	Maximum.	Mean.	Range.
	°C.	°C.	°C.	°C.
Air	18.3	30.8	24.5	12.5
Ground	14.9	47.8	31.2	32.9
Difference	−3.4	17.0	6.7	20.4

When compared with the table given by Hann[1] for the Indian station, Jaipur, it is found that the extremes at Kuibis are greater than those of the Indian station, partly because of its greater elevation and partly because of the great amount of sunshine. The minimum occurs about sunrise—in winter about 7 a. m. and in summer about 5 a. m. The maximum occurs about noon. The range of temperature between sunrise and noon in summer is about 60° C. and in winter is about 50° C. These

[1] *Meteorologie*, p. 48.